Sociometric Risk Networks and Risk for HIV Infection

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ABSTRACT

Objectives. This study examined whether networks of drug-injecting and sexual relationships among drug injectors are associated with individual human immunodeficiency virus (HIV) serostatus and with behavioral likelihood of future infection.

Methods. A cross-sectional survey of 767 drug injectors in New York City was performed with chain-referral and linking procedures to measure large-scale (sociometric) risk networks. Graph-theoretic algebraic techniques were used to detect 92 connected components (drug injectors linked to each other directly or through others) and a 105-member 2-core within a large connected component of 230 members.

Results. Drug injectors in the 2-core of the large component were more likely than others to be infected with HIV. Seronegative 2-core members engaged in a wide range of high-risk behaviors, including engaging in risk behaviors with infected drug injectors.

Conclusions. Sociometric risk networks seem to be pathways along which HIV travels in drug-injecting peer groups. The cores of large components can be centers of high-risk behaviors and can become pockets of HIV infection. Preventing HIV from reaching the cores of large components may be crucial in preventing widespread HIV epidemics. (*Am J Public Health.* 1997;87:1289–1296)

Introduction

Network analysis is an emerging field that helps explain human immunodeficiency virus (HIV) infection,[1–12] HIV-related risk behaviors,[2,3,10,11,13–17] and the spread of other infectious diseases.[18–20] Some network studies investigate subjects' "egocentric" risk networks—those with whom a subject engages directly in risk behaviors. Others, including this paper, look at "sociometric" network structures, composed of patterns of relationships involving risk behaviors among large numbers of subjects. Sociometric risk networks, which describe the direct and indirect linkages through which HIV and other similarly transmitted agents can be transmitted among persons at risk, provide a structural model for analyzing the kinds of linkages used in contact tracing.[1]

It has been argued that sociometric risk networks structure the flow of infectious agents in communities and thus provide unique opportunities for interrupting such flow.[9] Individuals' locations in such networks may determine the proportion of their contacts who are infected and thus may help determine their own probability of becoming infected. Sociometric network location, therefore, can define an aspect of HIV risk that cannot simply be reduced to the amount of high-risk behavior in which an individual engages. Network techniques, for example, might explain why race/ethnicity has often been found to be a significant predictor of HIV infection, even when risk behaviors are controlled.[21,22]

Network studies, including the determination of which network concepts are epidemiologically meaningful, are a relatively new area of HIV research.[23,24] They involve somewhat specialized data and categories that need to be described.

This paper uses a particular characteristic of sociometric network location: membership in the "2-core" of a large connected component. These terms are illustrated in Figure 1, where subjects fall into two connected components, one with eight members and one with two members. A connected component is a set of persons who all have direct or indirect links to each other. Two components are separate, therefore, if no member of one is linked to any member of the other. Within the eight-member component, there is a 2-core of five members who are each linked to at least two other 2-core members, while the other three members constitute the periphery of the large component. (The 2-core is, technically, a Seidman 2-core,[25] definable[26] in graph-theoretic terms as follows: A *k*-core is a subgraph in which each node is adjacent to at least a minimum number, *k*, of the other nodes in the subgraph.) Clearly, not only are 2-core members linked to other drug injectors, but many of these others are linked to still other drug injectors. Thus, the 2-core of a large connected component has the potential, if one or more members become infected, to act as

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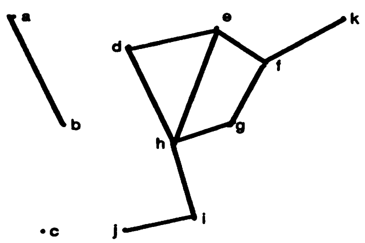

Note. Among these 11 subjects, one (c) is unlinked, and there are two separate connected components (one with eight members [d through k] and one with two members [a and b]). A connected component is a set of persons who all have direct or indirect links to each other. Two components are separate, therefore, if no member of either is linked to any member of the other. In the large connected component, d, e, f, g, and h form a Seidman 2-core since each is linked to at least 2 other members of this core. Subject i is not in this 2-core because i is linked only to one 2-core member, h. Subjects j, i, and k constitute the periphery of the large connected component.

FIGURE 1—Network structures.

a center of HIV transmission both within itself and also outward to periphery members.

The questions examined were whether in New York City, with its high seroprevalence among drug injectors, drug injectors in the 2-core were more likely to have been infected, and whether as-yet-uninfected drug injectors in the 2-core were at particularly high risk for future infection with HIV.

Methods

Subjects

Drug injectors were recruited through street outreach in areas with heavy drug use and through chain referral by other subjects, as described elsewhere.[3] They were interviewed (with informed consent) from July 1991 to January 1993 in the Bushwick community of Brooklyn. They were tested for HIV antibody (double ELISA with Western blot confirmation) and hepatitis B core antibody. Eligible subjects had to have injected drugs within the previous year. Since drug abuse treatment status was not an eligibility criterion, the sample includes both in-treatment and out-of-treatment drug injectors.

A face-to-face structured interview gathered data including subjects' sociodemographic and biographical background, drug and sexual risk behaviors during the previous 30 days and the previous 2 years, medical history, health beliefs, social roles in the drug scene, and networks.

Network Data

Subjects provided information about up to 10 persons with whom they had injected drugs or had sex during the previous 30 days, how long they had known each network member, the nature of their relationship, the network member's risk behavior, and their risk behaviors together.

Questionnaire and other data gathered during the project were used to define sociometric linkages among research participants. Such linkages were operationalized as follows. First, one or both subjects must name the other as someone with whom he or she had, in the 30 days prior to the interview, injected drugs or had sex. Second, confirmation was required that the named other person was in fact the one we interviewed. A link was considered confirmed if two participants engaged in face-to-face contact with research staff at the same time or were observed together in public settings by project ethnographic staff. Links could also be confirmed by matching selected characteristics reported by index subject A (first name or street name, age within 5 years, race/ethnicity, and gender) with descriptors of A provided by another subject who had nominated him or her (see Neaigus et al.[3]).

Defining Sociometric Network Location

UCINET software[27] was used to detect connected components and Seidman *k*-cores[25] within them. Since this analysis detected a single large connected component containing approximately one third of the research participants, we categorized participants into five structural categories to operationalize the concept of sociometric network location, as follows: (1) a 2-core of the large connected component (each two-core member is linked to two or more other members); (2) the periphery of the large component, composed of its other members; (3) members of smaller connected components; (4) members who nominated other injection drug users as persons with whom they had injected drugs or had sex within the previous 30 days but who were not linked to other participants in this project; and (5) unlinked injection drug users. These categories, then, form a scale of decreasing high-risk social connection to other injection drug users.

Statistical Analysis

The specific questions examined were (1) whether this five-category operationalization of sociometric network location is associated with HIV infection and HIV risk behaviors in univariate analyses; (2) whether, with risk behaviors and other known predictors controlled, 2-core members are more likely than nonmembers to be infected with HIV; (3) whether seronegative 2-core members are more likely to engage in high-risk behaviors than are other seronegative drug injectors; and (4) whether seronegative 2-core members are more likely than other seronegative drug injectors to engage in high-risk behaviors with linked seropositive drug injectors.

Relationships between sociometric network location and personal characteristics and risk behaviors were analyzed with the chi-square test for trend to provide an approximate indication of statistical significance. In analyses where sociometric network location was dichotomized into 2-core vs other, the Pearson chi-squared test was used. Logistic regression was used to test whether 2-core membership was an independent significant predictor of HIV serostatus. However, since HIV is by no means a rare disease among New York City drug injectors,[28] odds ratios in the logistic regressions are not indicators of relative risk.[29]

Statistical analysis was complicated by the sampling design, since the design includes both the street recruitment typical of studies of drug injectors and similar "hidden populations"[30] and chain referral to recruit nominated network contacts. Since there is no sampling frame or procedure that allows a street-recruitment probability basis, the subjects are not a probability sample of a population. Nevertheless, conventional statistical tests have often been used with street-recruited samples to provide an indicator of whether statistical associations are likely to be due to chance.[21,30–33]

Chain referral, for its part, violates the assumption of sampling independence, that is, that a population member's sampling probability is not a function of who else is sampled. It may also produce sampling bias, since those with many connections are more likely to be nominated by other subjects.[34] Theoretical statistical analyses and simulation-based studies indicate, however, that network studies can provide valid estimates of population parameters.[35,36] We used multiple initial index cases to reduce potential bias. Nonetheless, our early sampling tended to recruit the more visible members of the local drug scene. Furthermore, since early recruits had more time for their nominees to be recruited, there could be a methodologically induced tendency to classify them as members of the large connected component (and of its 2-core).

Since risk network research is a relatively new epidemiological technique, limitations on accuracy in ascertaining linkages, potential effects of inaccurate measurement of linkages, and the extent to which results might be affected by the number of subjects studied have not been determined. Sensitivity analyses were thus conducted to study whether findings would change if the data set were modified by (1) randomly deleting 20% of linkages; (2) deleting the last 20% of subjects to be interviewed (which tests effects of stopping the study before recruiting the last 20% of subjects); or (3) deleting the first 10% of subjects to be interviewed (which tests whether results are altered owing to either more time being available to recruit network contacts of these first subjects or recruiting the most visible—and perhaps most connected—drug injectors first).[14]

Results

Sociodemographic characteristics of the 767 interviewed drug injectors resemble those in other studies of New York City drug injectors (Table 1).[28]

TABLE 1—Characteristics of 767 Street-Recruited Drug Injectors in Brooklyn, NY, July 1991 through January 1993

	No. Subjects	%
HIV status[a]		
Negative	415	60
Positive	272	40
Hepatitis B core antibody status[a]		
Negative	165	28
Positive	426	72
Gender		
Male	541	70
Female	226	30
Race/ethnicity		
African-American (not Latino)	198	26
Latino (not Black)	255	33
White (not Latino)	243	32
Black Latino	58	8
Others	13	2
Years of injection		
<6	187	24
≥6	579	76
Homeless	153	20
With home	614	80
In drug abuse treatment	165	22
Not in drug abuse treatment	590	78
Ever in drug abuse treatment	529	69
Never in drug abuse treatment	238	31
	Mean	**SD**
Age, y	34.8	7.0
No. monthly injections during previous 2 years	112	139
Years of injection	13.8	9.0

[a]HIV antibody test results were unavailable for 80 participants because they decided not to undergo testing or because of the difficulties phlebotomists had in drawing blood from the veins of drug injectors. Among those for whom sera were available, 96 specimens were unable to be tested for hepatitis B core antibody because of insufficient quantity.

Sociometric Network Location

Of the 767 subjects, 309 were not linked to other injection drug users in the study. Of these, 183 had named another drug injector as someone in their network with whom they had had sex or injected drugs in the last 30 days.

Ninety-two connected components were identified. Sixty-eight were dyads, 14 had 3 members each, 4 had 4 members, 3 had 5 members, 1 had 7 members, and 1 had 12 members. A large 230-member connected component contained one 2-core with 105 members. Thus, sociometric network locations of participants were as follows: (1) 105 were within the 2-core of the large component; (2) 125 were within the periphery of the large component; (3) 228 were members of one of 91 other connected components; (4) 183 were unlinked but reported having injected drugs or having had sex with a drug-injecting network member in the previous 30 days; and (5) 126 were unlinked.

Sociometric Structure and Individual Attributes: Univariate Analyses

In cross tabulation, the five-category measure of sociometric risk connections was significantly related to a number of variables (see Table 2). Two-core members had a considerably higher probability of HIV infection than other subjects (57% vs approximately 37%). Hepatitis B core antibody—an indicator of previous infection rather than of continuing infectiousness—was also most prevalent among 2-core members.

Several injecting practices that have been associated with higher probability of HIV infection, including injecting with syringes others have used,[37,38] backloading (syringe-mediated drug sharing),[39] injecting in outdoor places[40] or shooting galleries,[41] and injecting cocaine or speedball,[42–44] were more likely to have been engaged in by drug injectors with greater sociometric linkage to other drug injectors. Similarly, such linkage was associated with more frequent injection of cocaine, heroin, and speedball (heroin and cocaine in combination). Crack use was also more common among subjects with more linkage to other injectors. Condom use, however, was not associated with sociometric location.

Sociometric location was also related to social roles in the street economy. Two-core members were significantly more likely to engage in syringe selling, and those in the 2-core or periphery of the large connected component were more likely to engage in commercial sex work, than were other drug injectors. Sociometric location, however, was not significantly associated with selling drugs.

Several measures of social stratification were also related to sociometric location: Homeless drug injectors, those who lacked legal income, and White drug injectors were more likely to be 2-core members. Latinos were more likely to be unlinked, which may reflect their

TABLE 2—Relationships between Sociometric Network Location and Other Variables for 767 Street-Recruited Drug Injectors in Brooklyn

	Category (Total n = 767)					
	Large Connected Component		Small Component (n = 228)	Unlinked[a]		
	2-Core (n = 105)	Periphery (n = 125)		With Risk Partner (n = 183)	Without Risk Partner (n = 126)	P[b]
Infection status, % (n)						
HIV-positive	57 (93)	35 (115)	37 (201)	39 (167)	36 (111)	.026
Hepatitis B core antibody–positive	84 (67)	74 (95)	71 (177)	71 (150)	68 (102)	.036
Characteristics, % (n)						
White	34 (105)	42 (125)	37 (228)	24 (183)	20 (126)	.001
Black	30 (105)	26 (125)	27 (228)	28 (183)	23 (126)	.444
Latino	34 (105)	30 (125)	35 (228)	48 (183)	56 (126)	.001
Female	30 (105)	30 (125)	31 (228)	27 (183)	29 (126)	.639
Homeless	30 (105)	24 (125)	17 (228)	16 (183)	19 (126)	.015
Lacking legal income	41 (105)	25 (125)	18 (228)	24 (183)	21 (126)	.003
New injector (<6 y)	18 (105)	16 (125)	18 (227)	21 (183)	29 (126)	.020
Engaged in specified behaviors in last 2 years, % (n)						
Receptive syringe sharing	61 (105)	52 (125)	51 (225)	49 (180)	27 (123)	.001
Backloading (syringe-mediated drug sharing)	51 (104)	30 (123)	22 (226)	23 (180)	9 (123)	.001
Injecting outdoors	70 (105)	60 (125)	39 (226)	50 (183)	34 (124)	.001
Injecting in shooting galleries	46 (104)	31 (124)	18 (225)	39 (181)	19 (123)	.003
Injecting cocaine or speedball	91 (104)	81 (124)	73 (226)	69 (180)	61 (122)	.001
Crack use	69 (105)	59 (124)	55 (227)	52 (181)	39 (123)	.001
Consistent condom use	21 (89)	18 (115)	13 (205)	19 (161)	12 (104)	.225
Role in drug scene, % (n)						
Selling syringes	30 (105)	15 (124)	14 (225)	17 (179)	11 (123)	.005
Selling drugs	18 (105)	21 (124)	14 (225)	23 (179)	20 (123)	.472
Engaging in commercial sex work	23 (103)	22 (119)	9 (223)	14 (175)	11 (121)	.003
Program contact, % (n)						
In drug abuse treatment	7 (105)	19 (124)	32 (225)	19 (178)	22 (123)	.020
Received in last 3 mo						
Bleach	71 (105)	56 (124)	50 (225)	57 (176)	45 (122)	.001
Sterile syringes	52 (105)	34 (124)	27 (225)	27 (177)	21 (122)	.001
Condoms	68 (105)	62 (124)	53 (225)	59 (176)	45 (121)	.001
Medical treatment	4 (105)	2 (124)	3 (225)	7 (177)	6 (123)	.109
AIDS-related talk and influence in last 30 days, % (n)						
Another user told subject to use bleach	71 (100)	54 (121)	47 (222)	51 (174)	38 (121)	.001
Subject told another user to use bleach	68 (100)	47 (121)	49 (222)	52 (174)	39 (122)	.001
Subject discussed AIDS with another user	60 (105)	52 (124)	55 (223)	52 (178)	27 (124)	.001
Continuous variables						
Years of injection (SD)	14.0 (8.4)	13.2 (8.3)	14.6 (9.5)	14.0 (9.2)	12.7 (9.2)	.537
Drug injection frequencies per mo in prior 2 y (SD)						
Cocaine	41.6 (77.3)	19.7 (48.6)	20.7 (53.2)	14.7 (44.0)	9.9 (40.3)	.001
Heroin	83.4 (91.7)	56.9 (73.3)	43.1 (55.4)	52.1 (63.3)	42.6 (60.6)	.001
Speedball	87.4 (99.4)	46.5 (83.4)	23.8 (51.5)	34.4 (64.6)	13.8 (44.6)	.001

Note. n indicates the sample size for which data were available for each variable for subjects in a given sociometric network location.
[a]As described in text, some participants who were not linked to others reported having injected drugs or having had sex with one or more network members in the previous 30 days.
[b]Probabilities by Mantel-Haenszel test for trend. For continuous variables, probabilities are by linear regression.

numerical predominance in the local drug scene.[11]

Two-core members were *less* likely to be in drug abuse treatment. HIV prevention programs such as syringe exchanges and programs that distribute bleach and condoms, however, seem to have reached drug injectors in the large connected component more effectively than those in smaller components or those who were unlinked. Perhaps as a result, 2-core members were more likely to have told others to use bleach to decontaminate their syringes and to have been told to use bleach, and the unlinked were least likely to have discussed AIDS with another drug injector. Thus, "passing the message on" occurred more often among drug injectors with more linkage to other injectors.

Multivariate Predictors of HIV Serostatus

Previously determined risk factors for HIV infection among subjects in this study[39] were entered simultaneously with sociometric location (2-core vs non-core) as potential predictors of HIV infection (Table 3). All variables except Black race/ethnicity, including sociometric location (odds ratio [OR] = 1.85), were significant predictors.

Additional equations were estimated after inclusion of additional risk-behavior variables: shooting gallery use, injection in outside settings, injecting with syringes used by other injectors, sharing rinse water, sharing cookers, crack use, and commercial sex work. In these equations, sociometric network location remained a significant predictor (data not shown). Finally, when the number of drug injectors that a subject had named in the network section of the interview was added to the equation in Table 3, sociometric network location (OR = 1.84) remained a significant predictor of HIV, but the number of drug injectors named by the subject was not itself a significant predictor ($P > .95$).

TABLE 3—Sociodemographic, Behavioral, and Sociometric Network Characteristics Predictive of HIV Serostatus among 673 Street-Recruited Drug Injectors in Brooklyn (Logistic Regression)

	Odds Ratio	95% Confidence Interval
2-core (vs all other)	1.85	1.11, 3.07
Black (vs White)	1.46	0.94, 2.28
Latino (vs White)	1.92	1.28, 2.89
Years since started injecting	1.06	1.04, 1.08
Behaviors in last 2 y		
Any backloading	1.55	1.04, 2.31
Speedball injection frequency (scale = 10/mo)	1.05	1.02, 1.07
Any woman-to-woman sex	2.38	1.06, 5.33
Any man-to-man sex	3.57	1.02, 12.5

Equation (−2 log likelihood) = 805.269
$\chi^2 = 95.339$
$P = .0001$

TABLE 4—High-Risk Behaviors in the Last 30 Days among 415 HIV-Seronegative Street-Recruited Drug Injectors in Brooklyn: Members of the 2-Core in the Large Connected Component vs Other Drug Injectors

	2-Core Members, % (n = 40)	Others, % (n = 375)	P (χ^2)
Receptive syringe sharing	45	35	.230
"Tasting" drugs from someone else's syringe	30	11	.001
Backloading (syringe-mediated drug sharing)	42	11	.001
Injecting in shooting galleries	22	15	.251
Injecting outdoors	65	29	.001
Injecting cocaine or speedball	90	57	.001
Sharing cookers	62	50	.129
Sharing rinse water	52	33	.013
Crack use	70	45	.003
Vaginal or anal sex without a condom	28	51	.007

Risk Behaviors of Seronegative 2-Core Members

Are seroconversions occurring while drug injectors are in the 2-core, or do drug injectors become 2-core members after becoming infected? Although cross-sectional data are limited in their ability to answer this question, Table 4 compares data on risk behaviors of the 40 seronegative 2-core members with those of 375 other seronegative research participants. Many seronegative 2-core members report risky behaviors in the 30 days prior to the interview. They were significantly more likely to engage in a range of injection- or drug-related risk behaviors than were other seronegative drug injectors (although less likely to engage in unprotected sex).

We compared (1) the extent to which 40 seronegative 2-core members engaged in high-risk behaviors with linked seropositive drug injectors with (2) the extent to which high-risk behaviors with linked seropositive drug injectors were engaged in by the 202 seronegative subjects who were either members of the periphery of the large component or members of smaller components. During the last 30 days, seronegative 2-core members were significantly more likely to have injected with a seropositive drug injector (67% vs 29%), to have shared a cooker with a seropositive drug injector (42% vs 19%), and to have shared rinse water with a seropositive drug injector (30% vs 15%). They were not, however, statistically distinguishable in terms of proportions who had injected with a syringe that a seropositive drug injector had previously used (15% vs 7%), who had had any sex with a seropositive drug injector (5% vs 8%), or who had had unprotected sex with a seropositive drug injector (2% vs 7%).

Sensitivity Analyses

In sensitivity analyses run within two of the reduced data sets (those with [1] random deletion of 20% of linkages and [2] deletion of the last 20% of subjects to be interviewed), the pattern of results was generally similar to that in the entire data set (data available from senior author). The similarity of results in these sensitivity analyses suggests that relationships between sociometric risk network location and dependent variables are quite robust.

The third sensitivity analysis was more complicated. With the first 10% of subjects deleted, no single "large" component predominated. The largest component had 46 members (and a 2-core of only 3 members); other components had 21, 15, 14, 12, and 8 members; 9 had 4 to 7 members; 14 had 3; and 74 had 2. Of the subjects, 337 remained unlinked. HIV seroprevalence was 38% both in the 46-member component and among the other 579 drug injectors with valid HIV test results in this data set (although members of the 46-member component were more likely to engage in risk behaviors than the other 579).

When we analyzed how the first 10% of subjects interviewed compared with the last 90%, we found that they were significantly more likely to be HIV seropositive (52% vs 38%), to sell drugs

(29% vs 18%), to sell syringes (33% vs 15%), and to engage in commercial sex work (31% vs 13%), as well as to inject with syringes used by other injectors, backload, and inject in outside settings.

Analyses were also run deleting all data for unlinked research participants who reported names of drug injectors with whom they had injected drugs or had sex in the previous 30 days. Results within this data set were generally similar to those in the entire data set (data available from senior author).

Finally, because persons within each category defined through network structure analysis may be similar, our estimated variances may actually be higher than is assumed by statistics based on simple random samples. This would, of course, be true had our original sampling design included a master list of all persons in the five sociometric network location categories (see Table 2) and if we had sampled from within the categories as if they were clusters. Had such been the case, the design effect, approximated using the binomial variance of the proportion of HIV-positive subjects within each cluster, would have been 1.08.[45] The low design effect suggests that, had our study sample been an a priori cluster sample, the effect on variance estimates would have been small.

Discussion

Limitations

First, as in all studies of hidden populations, it is impossible to select a random sample of drug injectors.[30] Second, subjects may have underreported the number of persons with whom they had injected or had sex in the last 30 days. Such underreporting of contacts might have affected the representativeness of study participants or the completeness of data about linkages among participants. Underreporting of linkages might also have led us to misclassify some 2-core members as non-core members. However, we see no reason why seronegative 2-core members would be more likely than seropositive ones to be misclassified. Further, such misclassification would probably have a conservative impact: By reducing the strength of the observed relationship between 2-core membership and HIV serostatus, it would make analyses less likely to find them to be related.

These data are somewhat limited for analyzing risk factors for prevalent HIV infection in New York City, where the epidemic was 15 years old. Although both risk behaviors and social networks will have changed during this period, network data were based primarily on questions about linkages during the previous 30 days and on behavior within these linkages, and behavioral data described activities during either the previous 30 days or the previous 2 years. Seropositive subjects would almost certainly have been infected before the last 30 days. Thus, it is impossible to be sure about the direction of causation. For example, risky behaviors early in participants' injection careers might have led first to HIV infection and only later to injecting with 2-core members.

Although self-report data may sometimes be imprecise, comparisons of self-reports with what other respondents report about subjects have shown these data to be reliable.[46] Furthermore, relationships between independent and dependent variables that are in accord with those predicted by theory provide construct validation for a number of these variables.[2,3,10,11,39,40,47]

Finally, the sensitivity analyses suggest that, although further research on sampling techniques and ascertaining linkages is desirable, the issues of unmentioned linkages and of failure to recruit another hundred subjects at the end of a sizable study are not likely to be crippling problems for the types of analyses conducted in the present study. The difference in component structure when the first 10% of subjects recruited were deleted, however, has both substantive and methodological implications. Substantively, it suggests that (at least in large semipublic drug scenes in high-prevalence areas) the most visible members of drug-injecting networks may be more likely to be infected and to engage in risk behaviors, and that they may play key linking roles in transmitting infections and, perhaps, in diffusing social influence. Methodologically, it means that network studies should not assume that recruiting a simple random sample of drug injectors is ideal. Since the most visible drug injectors may have a special role in the spread of both viruses and influence, studies might best use stratified sampling to ensure including a sufficient number of the most visible. In practice, however, probability sampling of street injectors is not possible, and targeted sampling[30] and other procedures already recruit adequate samples of the most visible. This is suggested by the fact that major network studies of drug injectors in Colorado Springs, Colo, and Flagstaff, Ariz, also found a single large component plus some smaller components.[48]

Implications for HIV Transmission

Sociometric risk-network location is an independent predictor of prevalent HIV serostatus among drug injectors in New York, a high-prevalence city. (This conclusion needs to be tempered in light of limitations posed by cross-sectional study designs.) Nonetheless, many drug injectors have probably become infected while they have been 2-core members, since many uninfected 2-core members engage in syringe sharing and other high-risk behaviors with infected drug injectors. The 2-core is probably a locus for HIV transmission both among its members and from them to members of the periphery of the large component. Furthermore, sociometric risk networks are likely to be the pathways through which HIV (and other blood-borne infections) spreads throughout a community of drug injectors—both within the large component and, over time, from the large component to other drug injectors or sexual partners who come into contact with infected members or ex-members of this component. Thus, 2-cores may serve as core groups that can both maintain an epidemic and provide an epicenter for transmission to other drug injectors or sex partners.

The 2-core is only one measure of high-risk connection to other drug injectors. Other measures, such as 3-cores and centrality, also exist. In preliminary analyses, three 3-cores were found within the 2-core, with 4, 4, and 21 members, respectively, and 3-core membership appears to be related to HIV risk behaviors and infection. High-centrality members of the large connected component may also be more likely to engage in risk behaviors and to be infected.[49]

A comparison with findings from network studies in Colorado Springs, a city where HIV seroprevalence among drug injectors is only 8%,[6] provides a useful perspective.[4,7,10,34] In Colorado Springs there is a large connected component. Unlike in New York, however, HIV has not penetrated this core—and HIV has not spread widely. This suggests that one should not generalize that membership in the 2-core of a large connected component is a risk factor for HIV infection. Instead, it suggests that if infection becomes established within such a 2-core, it may lead to epidemic spread. It also suggests that prevention efforts in cities like Colorado Springs should concentrate on preventing core members from becoming infected by targeting core members and the periphery of the large component for risk reduction efforts (as well as targeting potential bridge groups such as gay and bisexual men who inject drugs). In high-prevalence areas like Bushwick in New York City, however, HIV is already present in all network locations, so prevention efforts should include all drug injectors and their sexual partners.

Further epidemiological research should include cross-sectional studies and cohort studies to determine (1) conditions under which sociometric network location is a risk factor for HIV seroconversion; (2) how other aspects of sociometric structure affect HIV seroconversion; (3) what combination of behavioral and network variables, and perhaps of biological resistance to infection or low levels of infectivity among some infected drug injectors, accounts for the continued presence of seronegative drug injectors who engage in high-risk behaviors with infected partners; and (4) whether and how sociometric risk networks are themselves shaped by characteristics of local urban structure, by policies on syringe possession or over-the-counter syringe sales, and by police strategies.

Implications for Risk Behavior and Prevention

Sociometric risk networks may affect both the probability that an individual will become infected with HIV and whether or not a large-scale HIV epidemic will occur among drug injectors in a community. Further, sociometric risk locations with greater connection to other drug injectors are characterized by more high-risk behavior. Possible mechanisms for such increased high-risk behavior include having more social interaction with other drug injectors and thus being more likely to ask or be asked to share injection equipment. Engaging in high-risk behavior may, conversely, help shape individuals' sociometric risk network locations. Cohort studies might help resolve these issues.

Research is needed on how risk-network findings might strengthen efforts to reduce the spread of HIV infection. Key issues include (1) finding cost-effective, practical ways for programs or drug injectors themselves to identify sociometric risk-network components and cores[11,13,50]; (2) determining whether it is possible to work with drug injectors to influence the size and structure of components of sociometric risk networks, and the effects of such changes on HIV transmission; (3) determining how to decrease the rate of entry of drug injectors (and particularly of new injectors) into large components or the 2-cores of such components, and the effects of such changes on HIV transmission; (4) determining how components or cores can become centers for promulgating and enforcing norms and values that support risk avoidance or risk reduction (although risk reduction advice is already given widely in the 2-core, risk behavior nonetheless remains higher there [see Table 2]); and (5) the relative efficacies and costs of sociometric network interventions, interventions using the personal (egocentric) networks of individual drug injectors,[51] and current intervention modes such as outreach, syringe exchange, recruiting drug injectors to drug abuse treatment, and HIV counseling and testing.

In conclusion, studying sociometric risk networks can help us understand the spread of HIV infection within communities of drug injectors. It may also help us develop new ways to reduce transmission in high-prevalence cities and to prevent epidemic outbreaks in low-prevalence cities. Such innovations are sorely needed. In areas where HIV prevalence remains low, changes in risk networks and risk behaviors might spark rapid transmission; half or more of drug injectors in a locality can become infected within a single year.[52,53] In high-prevalence cities such as New York, in spite of existing prevention efforts, seroconversion rates among drug injectors remain at 2.5% to 8.0% per year,[21,54,55] and even frequent participants in syringe exchanges seroconvert at a rate of 1.5% to 2.0% per year.[56] Network interventions to supplement existing programs might prevent many new infections. □

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